AN OVERVIEW OF THREE APPROACHES TO MULTIDISCIPLINARY AEROPROPULSION SIMULATIONS

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SUMMARY

The broad scope of aeropropulsion multidisciplinary applications necessitates that a collection of approaches, with distinct capabilities, be developed. Three general approaches to multidisciplinary simulations have been identified. The three approaches; *loosely coupled, coupled process,* and *multiphysics,* provide a comprehensive collection of capabilities for multidisciplinary aeropropulsion analysis. At the data access level, or *loosely coupled approach* of coupling, existing disciplinary simulations are run, data is generated, and made available and used for subsequent analysis. The data must be in the correct format for implementation by the subsequent analysis but the subsequent code need not directly communicate with the previous code. At the process level, or *coupled process approach* of coupling, individual disciplinary codes are used, similarly to the loosely coupled approach, however, in the coupled process approach the disciplinary codes need to run concurrently with each other. The system of equation coupled approach, or *multiphysics approach,* addresses those applications whose characteristics require that the disciplines be coupled at the fundamental equation level to accurately, or more efficiently, capture the multidisciplinary physics of the problem. No one of these approaches, by itself, addresses all of the community needs in this area. However, collectively the three approaches encompass all of the multidisciplinary applications which have been identified thus far. Multiple approaches to multidisciplinary simulations will be needed as long as the applications and their requirements remain as diverse as they currently are today.

INTRODUCTION

The broad scope of aeropropulsion multidisciplinary applications necessitates that a collection of approaches, with distinct capabilities, be developed. A process for developing these capabilities is to identify specific applications, which provide requirements and focus, and then to use this information as a basis for the development of the capabilities. By following this process, three general approaches to multidisciplinary simulations have been identified. The purpose of this report is to provide a summary of both the development and implementation of these approaches.

Figure 1 shows the three coupling approaches which are being pursued for aeropropulsion multidisciplinary applications. Also shown are the *levels of fidelity* and five projects under this area. The *levels of fidelity* range from the zero dimensional (parametric) up to the full three dimensional transient types of simulations. The five projects tend to be more heavily weighted towards the higher fidelity types of simulations because often it is not until these levels are reached that multidisciplinary effects have an impact. For example a low level aerodynamic analysis would not even include blading effects whereas a high level analysis might include not only the aerodynamic blading effects but also the interactions between the blading aerodynamics and structures.

At the data access level, or *loosely coupled approach* of coupling, disciplinary simulations are run, data is generated, and made available and used for subsequent analysis. The data must be in the correct format for implementation by the subsequent analysis but the subsequent code does not need to directly communicate with the previous code. For example, a structural analysis may be used to determine the deformed shape of a blade, then the deformed blade shape is used for a subsequent aerodynamic simulation. Obviously, for the process to be successfully performed it is required that the deformed blade shape generated by the structural analysis be interpretable by the aerodynamic analysis code.

Another characteristic of the loosely coupled approach is considerable user interaction typically is required to perform the simulation. Since the loosely coupled applications primarily involve higher level, more complicated, simulation capabilities, significant user expertise and involvement typically is required to successfully perform each of the individual disciplinary analysis. As a result, a loosely coupled simulation normally requires both the involvement of a disciplinary expert and a significant portion of time to de-bug and run each of the disciplinary codes.

At the process level, or *coupled process approach* of coupling, individual disciplinary codes are used, similarly to the loosely coupled approach, however, in the coupled process approach the disciplinary codes need to run concurrently with each other. For example, to perform a transient blading forced response analysis, the aerodynamic code is used to compute pressure loadings which are used by the structural analysis code to determine the motions of the blade. The blade motions then are fed back to the aerodynamic analysis where updated pressures are computed. This procedure typically is repeated thousands of times for a transient simulation since an aerodynamic-structural iteration is performed at least once during every time step and thousands of time steps are needed to capture a realistic transient behavior. The process is further complicated due to convergence requirements which dictate that the aerodynamic time steps be significantly smaller than the structural time steps. As a result of the large number of interdisciplinary interactions which take place, a large amount of user intervention is impractical, and a *coupled process approach* where both aerodynamic and structural codes are concurrently running and the data exchange between them is fully automated is required.

The system of equation coupled approach, or *multiphysics approach,* addresses those applications whose characteristics require that the disciplines be coupled at the fundamental equation level to accurately, or more efficiently, capture the multidisciplinary physics of the problem. The *coupled process approach* may be applicable to this class of applications, however, the *coupled process approach* requires that specialized tools be developed to exchange and manage data among disciplinary codes. Furthermore, the specialized tools often are unique to the particular application and are inapplicable, or require extensive modifications, before they can be applied to other problems. The *multiphysics approach* overcomes this limitation by providing a single code containing all the necessary disciplines thus eliminating the need for data exchange and the associated data exchange tools.

LOOSELY COUPLED APPROACHES

Coupled Aerodynamic Thermal Structural (CATS) Project

The first activity being pursued under the *loosely coupled approach* is the Coupled Aerodynamic Thermal Structural (CATS) Project. The objective of this project is to streamline multidisciplinary analysis of aeropropulsion components and assemblies. Multidisciplinary analysis of axial flow compressor performance has been selected for the initial focus. The project will permit more accurate compressor system analysis by enabling CATS users to include thermal and mechanical effects as an integral part of the aerodynamic analysis of the compressor primary flowpath. Thus, critical details such as the variation of blade tip clearances and the deformation of the flowpath geometry, can be more accurately modeled and included in the aerodynamic analyses. The benefit of this coupled analysis capability is (1) improved performance and stall line predictions through the inclusion of tip clearances and hot geometries, (2) an analysis tool enabling design alternatives to be readily analyzed, and (3) an analysis tool for higher fidelity disciplinary analysis.

The CATS project is implementing a *loosely coupled approach* because this approach is most similar to existing design/analysis practices. While the end users of the CATS project products seek to enhance their analytical capabilities, they also desire minimal modifications to their existing design/analysis practices. To accommodate this requirement, the CATS project is undertaking an approach of maintaining the usage of existing aerodynamic and structural analysis codes and developing data exchange tools for facilitating the process of exchanging data among these existing codes. The end user will be responsible for actual application of the disciplinary codes and data exchange tools.

The initial focus of the CATS project has been on streamlining the aerodynamic-structural analysis of compressor blading (fig. 2). During each analysis cycle pressures are computed using an existing aerodynamic CFD solver. An **Aerodynamic Surface Data Mapper** then is used to map the aerodynamic pressures onto the blade geometry. A structural blade pre-processor, **SABER**, is used next create a finite element mean camber model with pressure loadings from the loaded blade geometry. A structural finite element analysis is performed and the resulting blade deformations are post-processed, using SABER again, but this time to generate a deformed blade geometry. Finally,

the deformed blade geometry is used as input to an aerodynamic grid generator to create an aerodynamic grid from the deformed geometry. The entire process is repeated until a converged set of fluid and structural results are obtained.

The CATS tools make use of Non-Uniform Rational B-Spline (NURBS) technology to represent blading geometry and analysis results. A capability within this technology is a Geometry-Grid-Analysis (GGA) object which provides the ability to curve fit analysis results, such as pressures or displacements, and to "attach" those results to the geometry. One of the advantages of the NURBS technology is that it provides the ability to integrate the geometries used by industrial CAD/CAM systems with the analysis results generated by fluids, thermal, and structural codes into an integrated design system.

The initial phase of the CATS project has been demonstrated by performing Aerodynamic-Structural iterations on the Lewis Research Center Rotor37 test rig using aerodynamic, structural, and the CATS tools. During each analysis cycle, aerodynamic pressure and temperature data along with structural blade deforma-tions were computed. Previously, one cycle required a person-week to map data between aerodynamic and structure analysis codes and the design geometry. With the CATS tools the time was reduced to only several minutes. The current project plans are to continue development of the CATS tools and to integrate these tools into a common user interface. As progress is made on the project, additional efforts will be placed on applying these tools to aeropropulsion applications.

CFD-Controls Project

The second project under *loosely coupled approach* is the CFD-Controls project. The long term objective of this project is to enable the use of high fidelity CFD codes for controls system design (refs. 1 to 3). Historically, empirical data or low level fluid codes (e.g. lumped-parameter) have been used for control system analysis. However, CFD codes provide an opportunity for providing higher fidelity control system simulation, especially for high speed propulsion systems systems like the high speed civil transport (HSCT). The nearer term approach of this project is to use CFD codes to provide steady state data which then is used to generate the characteristic matrices for the controls models. The accuracy of the controls models are validated with transient CFD analysis results.

There are three main elements which enable the utilization of CFD for control system design (fig. 3). One element is *reduced order modelling*, where data from CFD simulations are linearized, then reduced from the large number of degrees-of-freedom normally employed for CFD simulations to the smaller number of degrees-of-freedom practical for control system modelling. Another element is CFD technology where CFD codes are enhanced to meet the need for time accuracy with realistic boundary conditions and reasonable turn around times. The final element is implementation of a user interface to simplify the use of CFD codes by non-CFD experts.

In the area of *reduced order models*, reduction methods have been developed for 1-D, 2-D, and 3-D CFD simulations. If an acceptable number of degrees of freedom used by the control model is established for a given control system, then higher order CFD models such as those found in three dimensional models, must be reduced by a larger amount than smaller CFD models. For example, while a 1-D CFD model may require a 10:1 reduction in size to accommodate the control model, a 3-D CFD model may need a 10000:1 reduction. To date, reduction software (implemented with MATLAB, (ref. 4)) has been developed, and validated with a HSCT-type inlet concept, using the 1-D LAPIN[5] code. Preliminary software also has been developed for use with the 2-D and 3-D NPARC (ref. 6) CFD codes. A method for generating reduced order linear models from 1-D CFD has been documented (ref. 7).

In the area of CFD codes, a number of capabilities have been implemented and validated using two-and three-dimensional versions of the NPARC code. Time accuracy of the code was validated (ref. 8) and a capability for specifying boundary conditions as a function of time was added. A compressor face boundary condition (ref. 9) has been developed to more accurately simulate the effect that an engine has on the transient fluid flow in an inlet. Additionally, a moving grid capability (ref. 10) has been developed for the 2D NPARC code. This capability makes it possible to accurately simulate inlets with translating/collapsing centerbodies, such as those found in high speed aircraft engine concepts. The transient capabilities of both the LAPIN and NPARC CFD code, have been used to assess the accuracies of the reduced order models.

In the area of user interfaces, a CFD user interface is being developed to simplify the use of CFD codes by non-CFD experts so that the appropriate CFD data can be extracted and used by control design engineers with little CFD background. The interface provides a graphical means for interactively controlling and monitoring the CFD code(s) and extensive database management capabilities for archiving results. The interface is based on other software being developed at NASA Lewis as part of the integrated CFD and Experiments (ICE) project (ref. 11) and has been

demonstrated with the 1-D LAPIN code. Current interface work is focused on using object-oriented technologies, such as C^{++} and CORBA, to increase interface portability and simplify expansion for use with the 2D and 3D NPARC codes.

COUPLED PROCESS APPROACH

Mechanical System Analysis/Design Tool (MSAT) Project

The objective of this project is to develop a software tool to facilitate preliminary design for propulsion system mechanical geometry generation (refs. 12 and 13). This tool will include interfaces to existing geometry generation, weight, cost, and life prediction codes. Preliminary design criteria and engine cycle data will be used as input. A graphical user interface for selecting parts, combining them into a configuration, and applying design specifications will be provided. The software will include provisions for design components, analysis modules, and links for connecting modules together and applying constraints. An interface to an optimizer and a visual capability for viewing design alternatives will be provided. Incorporation of mechanical design capabilities into the propulsion system cycle design process provides an enhancement to the preliminary design process. Through the inclusion of mechanical design parameters, such as component weights and costs, higher fidelity preliminary designs may be produced.

The MSAT project is classified as a *coupled process approach* because the coupling is among existing application codes and the coupling is automated. Since it is required to evaluate many design options during preliminary system design, it is impractical to run each of the individual application codes (e.g. aerodynamic, mechanical, cost, etc.) then manually exchange data from one application code to the next to determine overall system effects. Instead, an automated tool for data exchange is required so that the greatest number of possible tradeoffs may be investigated.

Design using the MSAT environment begins with the construction of a candidate engine configuration. A graphical user interface is used to browse a library of object classes representing various engine components and analysis modules. As the desired components are instantiated, the user is prompted to indicate the topology of the configuration by indicating how components are geometrically attached to one another. The connections between components are modeled using a third category of objects called design links. The links defined in the MSAT library determine which components may be connected together, and specify the relationships between the attributes of connected objects.

Figure 4 provides an example of how a design configuration is generated using MSAT. In this example, an engine component (an object) is created for a turbine. The design attributes associated with the turbine object are mechanical variables such as radius and weight and aerodynamic variables such as efficiency. Analysis programs (also objects) are created for aerodynamic and mechanical analysis. These objects are attached to existing analysis codes and contain the appropriate attributes required to actually run the code and provide design data back to the turbine component. Finally, link objects are used to connect the turbine component to the two analysis programs.

Design studies may be performed once the configuration model is completed. Studies are performed by the user setting initial values for select attributes. Next, MSAT, through a technique termed constraint propagation, determines which of the other attributes are effected by these changes and executes the necessary analysis programs to update the effected attributes. The user then can review the results and make another round of modifications to selected attributes.

The MSAT tool has been used for two aeropropulsion applications. The first is for an exhaust nozzle design for a High Speed Civil Transport. In this application, MSAT is used to evaluate the nozzle mechanical design by coupling a series of analysis modules that compute pressures along the nozzle components to structural representations of the nozzle mechanical parts. The nozzle mechanical flap attributes (e.g. thickness) are determined by coupling the pressures computed by the fluid flow code to stress predictions generated by structural analysis. The second application of MSAT is for a Robust Design Aide being developed jointly by GE Corporate Research and GE Aircraft Engines. In this application MSAT is used both as an integrator for aircraft engine preliminary design codes and as an executive manager to optimize preliminary designs and determine design robustness based on uncertainties in the design parameters.

Visual Computing Environment (VCE)

The goal of the Visual Computing Environment (VCE) is to develop a software framework for use in intercomponent and multidisciplinary computational simulations (refs. 14 and 15). Many engineering analysis codes exist today which simulate various aspects of aircraft engine operation. For example, computational fluid dynamics codes exist which model the air flow through the individual engine components such as the inlet, compressor, combustor, turbine, or nozzle. Currently, these different codes are run in isolation, making intercomponent and complete system simulations very difficult to perform. In addition, management and utilization of these engineering codes for coupled component simulations is a complex, laborious task, requiring substantial experience and effort. In order to facilitate multi-component and multidisciplinary aircraft engine analysis, a system known as the Visual Computing Environment (VCE) is under development by CFD Research Corporation (CFDRC). VCE enables coupling of various engineering disciplines such as CFD, structural, and thermal analysis.

The VCE project is classified as a *coupled process approach* because, similarly to the MSAT project, the coupling is among existing application codes and the coupling is automated. The VCE project differs from the MSAT project in that the VCE project focus is on higher level simulations. While the MSAT capability deals primarily with the exchange of simple design variables (e.g. component weight) among application codes, the VCE software must accommodate the complex data (e.g fluid flow results from the boundary of a component fluid grid) associated with high fidelity simulations. Furthermore, the VCE software must manage the execution of the applications in a way which ensures that the indiviudal simulations are in equilibrium with each other. With the MSAT capability, each application runs to completion before it passes results to the next application. With VCE, each application may only run for a prescribed number of increments before it passes and recieves results to ensure converged and accurate coupled simulations.

The visual computing environment is designed to provide an object oriented environment for coupling codes and performing intercomponent and multidisciplinary simulations (fig. 5). An Object Description Language (ODL) is provided to enable the creation of objects. Defining objects with VCE is similar to writing class definitions in an object oriented programming language. The application programmer who designs an object specifies the data associated with the object (e.g. grids, boundary conditions and solution data) and the functions that operate on object (e.g. compute fluid results and send or receive data). Actual simulations are performed by using a scripting facility which allows the end user to program the system, and link together objects, by invoking the functionalities provided by the objects.

Several usages of VCE are underway, showing validation of the basic design and areas needing further development. VCE is being used as part of the National Combustor Code (NCC) project by NASA Lewis, P&W, and CFDRC, for integrating grid generator, flow solver and visualization capabilities into one integrated environment. NASA Ames is using VCE as an interface tool and remeshing environment for deformable and moving body simulations (fig. 6). Under this project, VCE is used to tie the necessary tools (grid generator, flow solver, and visualization) together to predict the effect of wing angle of attack on fluid flow results. NASA LeRC is using VCE to integrate inlet and engine fluid flow simulations. For this application the NPARC code is being coupled to the ADPAC code. The plan is for both codes to run in their parallel modes on distributed workstations and for the code coupling to be across multiblock fluid domains. Lewis Research also is using VCE to couple an engine seal flow code to a main gas path code to better predict the interactions between the seal and main gas path fluid flows.

MULTIPHYSICS APPROACH

Spectrum Project

The goal of this project is to evaluate the Spectrum code using a series of NASA Lewis in-house, as well as industry selected test cases and to assess the potential use of this code as an industry tool for multidisciplinary simulations (refs. 16 and 17). Spectrum, a product developed by Centric Engineering Systems, Inc., establishes a new paradigm in mechanical simulation. It combines the ability to include fluids, structures, and their interactions with each other in a single-pass simulation. In this simulation the engineer can capture the true multiphysics behav-

ior of products. Furthermore, this is accomplished in one software program in a single simulation run. Instead of a collection of existing codes, *Spectrum*'s multiphysics capabilities are provided within the fundamental equations used to characterize the problem.

While CAD and CAE tools have evolved to assist in the design automation effort, the foundation for the current set of tools is rooted in dated technology. In addition, these tools are operationally complex and require high levels of support. Furthermore, most analysis codes focus on a single physics aspect of the design, so limited multiphysics simulations must be conducted using many tools which were not designed to work together. With Spectrum there is no longer the need to use multiple programs to solve multiphysics problems. Spectrum is classified as a *multiphysics approach* because all of the disciplines are represented in a single set of equations. In fact, Centric Engineering coined the term *multiphysics*.

For the initial phase of this project, Industry (Pratt & Whitney and Allied Signal) and LeRC have identified four problems to benchmark the code. The four problems are (1) Quenching Problem, (2) Drum Rotor problem, (3) Rim Cavity problem, and (4) a centrifugal compressor simulation. The main objective of the quenching problem (fig. 7) is to match thermocouple measurements taken on a test specimen during disk quenching. Initially, a coupled heat transfer analysis of the hot solid disk which is immersed in a cool fluid bath will be performed. Heating from the disk and buoyancy effects will establish a transient thermally driven flow in the fluid, while the disk cools in the oil bath. Deliverables will include the time histories of temperature in the disk at the thermocouple locations used in the experiment, as well as a set of visualizations of the transient flow velocities in the fluid and the temperature distribution in both the solid and the fluid.

The objective of the drum rotor internal flow problem is to simulate the fluid flow inside a turbomachinery drum cavity and to compare the simulation to published results. Since the flow velocities are moderately low (Mach number < 0.4) the fluid can be modelled as being incompressible. In addition, the point where the flow is injected will be approximated as a circumferential slit, so that the geometry can be treated as being axisymmetric. Centric will use Spectrum on a transient isothermal rim injection problem extracted from published data. The same grid will be used for three test cases to test Reynolds number response in the solver. The results will be summarized by transient visualizations of pressure and velocity in the injection and non-injection cavities and visualization of the axial-radial velocity field.

The objective of the turbine rim seal problem is to evaluate the *Spectrum* code for turbine cavity/rim seal simulations. A complete simulation will allow designers to examine the coupled fluid-thermal-structural interactions among the seal and seal related components. For example, changes in seal gaps resulting from mechanical and thermal effects, and the interaction between the seal flow and primary gas path flow, may be assessed. Seal flow simulations are complicated by the need to model both the secondary air flows below the blade platform, the main gas path flows, and the interactions among stages, seal cavities, and thermal and mechanical effects. For the first phase of this project, the *Spectrum* code will be compared to published rig data where the rig consists of a disc cavity which is injected with purge flow, a main gas path flow (without blading), and a configurable seal gap which is adjustable in both the radial and axial directions. Test results were generated for four seal gap configurations and several combinations of purge flow, cooling effectiveness, and rotational speeds.

The objective of the compressor main gas path problem is to simulate the fluid flow for a centrifugal compressor. This problem was selected because it provides a first step towards the ultimate goal which is to perform multiphysics simulations of complete engine systems including the interactions among main and secondary gas path fluid flows and thermal-structural responses of the mechanical parts. Since the largest challenge for the *Spectrum* code probably is in the simulation of the main gas path flow, it was decided to address this element of the simulation up front. The first step will be to perform an incompressible, isothermal analysis. The solution obtained from this analysis then will be used to formulate the pressure and velocity initial conditions for the subsequent compressible simulation. Visualizations of streamlines, surface temperatures and pressures, velocity vector slices at different plane locations, will be provided and compared with test data and/or other CFD results.

CLOSING REMARK

The three approaches; *loosely coupled, coupled process,* and *multiphysics,* provide a comprehensive collection of capabilities for multidisciplinary aeropropulsion analysis. No one of these approaches, by itself, addresses all of the community needs in this area. However, collectively the three approaches encompass all of the multidisciplinary applications which have been identified thus far. Multiple approaches to multidisciplinary simulations will be needed as long as the applications and their requirements remain as diverse as they currently are today.

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REFERENCES

1. Melcher, K.J., "An Overview of the Lewis Controls/CFD Interdisciplinary Research Program." Computational Aerosciences Workshop, Santa Clara, CA, March, 1995.

2. Cole, G.L., Melcher, K.J., Chicatelli, A.K., Hartley, T.T., and Chung, J., "Computational Methods for HSCT-Inlet Controls/CFD Interdisciplinary Research," AIAA paper 94–3209, June, 1994.

3. Chicatelli, A.K., Hartley, T.T., Cole, G.L., and Melcher, K.J., "Interdisciplinary Modeling Using Computational Fluid Dynamics and Control Theory," Proceedings of the 1994 American Controls Conference, Baltimore, MD., June, 1994.

4. MATLAB User's Guide, The MathWorks, Inc., Natick, Ma, 1993.

5. Varner, M.O., Martindale, W.R., Phares, W.J., Kneile, K.R., and Adams, J.C. Jr., "Large Perturbation Flow Field Analysis and Simulation for Supersonic Inlets," NASA CR–174676, Sept., 1984.

6. Cooper, G.K. and Sirbaugh, J.R., "The PARC Code: Theory and Usage", AEDR–TR–89–15, Dec., 1989.

7. Chicatelli, A. and Hartley, T., "A Method for Generating Reduced Order Linear Models of Supersonic Inlets," NASA CR–198538, January 1997.

8. Chung, J., "Numerical Simulation of a Mixed-Compression Supersonic Inlet Flow", AIAA 94–0583, January 1994.

9. Chung, J. and Cole, G.L., "Comparison of Compressor Face Boundary Conditions for Unsteady CFD Simulations of Supersonic Inlets," AIAA 95–2627, June 1995, NASA TM–107194, March 1996.

10. Freund, Donald, Sajben, Miklos, and Slater, John W., "Compressor-Face Boundary Condition Experiment: Generation of Acoustic Pulses in Annular Ducts," AIAA 96–2657, July, 1996.

11. Babrauckas, Theresa L. and Arpasi, Dale J., "Integrated CFD and Experiments Real-Time Data Acquisition Development," ASME 93–GT–97, May 1993.

12. Kolb, Mark A.,"An Object-Oriented Framework For Multidisciplinary Robust Preliminary Design," 6th AIAA/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, September 1996.

13. Kolb, Mark A. And Bailey, Michael W.,"FRODO: Constraint-Based Object-Modeling for Preliminary Design," Proceedings of the 19th ASME Design Automation Conference, Volume 1, pp. 307–318, September 1993.

14. Kingsley, G., Harrand, V., Lawrence, C.,"A Visual Computing Environment for Computational Aerosciences," 3rd Annual Computational Aerosciences Workshop, August 1996.

15. Visual Computing Environment User's Manual, CFD Research Corporation, Huntsville, Al., 1996.

16. Spectrum Theory Manual, Centric Engineering Systems, Santa Clara, CA, 1994.

17. Spectrum Users Manual, Centric Engineering Systems, Santa Clara, CA, 1994.

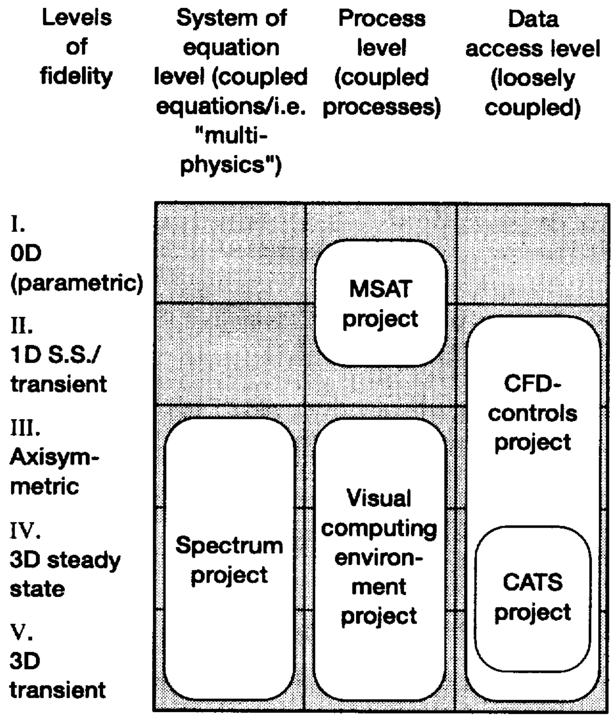

Figure 1.—Multidisciplinary coupling approaches.

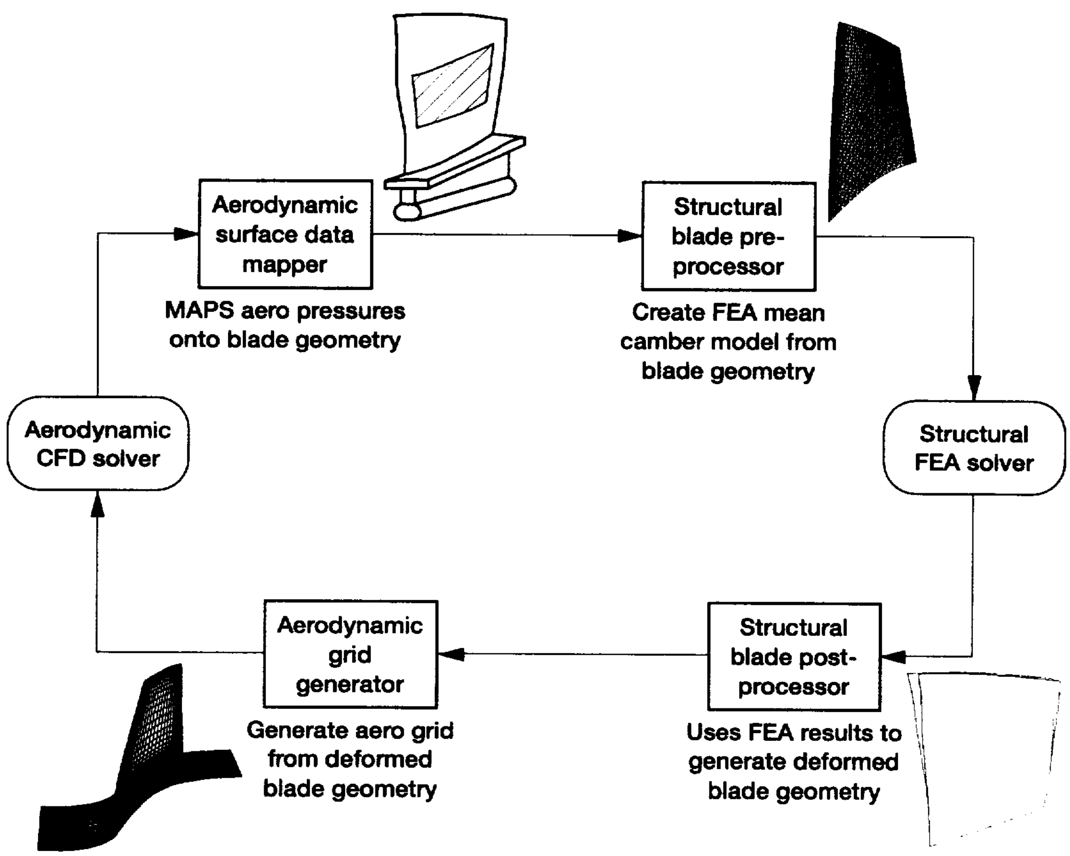

Figure 2.—Multidisciplinary compressor blade simulations.

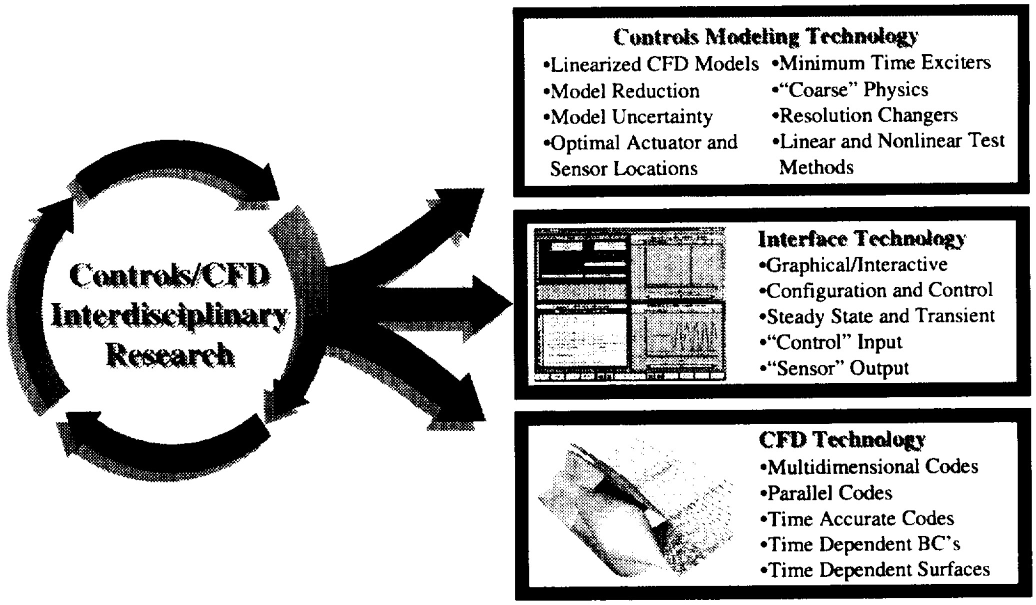

Figure 3.—CFD/controls project.

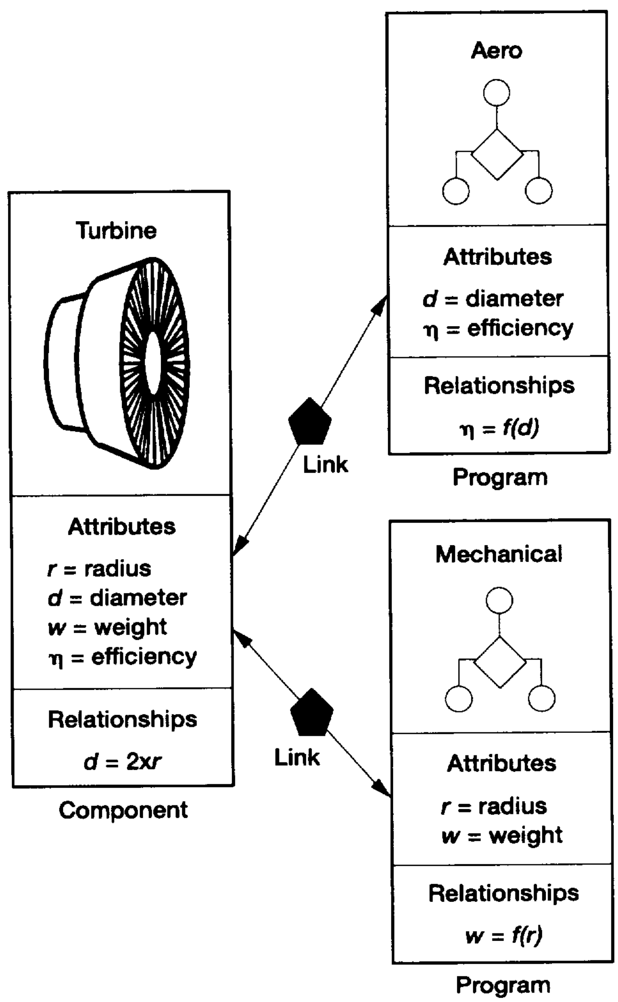

Figure 4.—MSAT component linking.

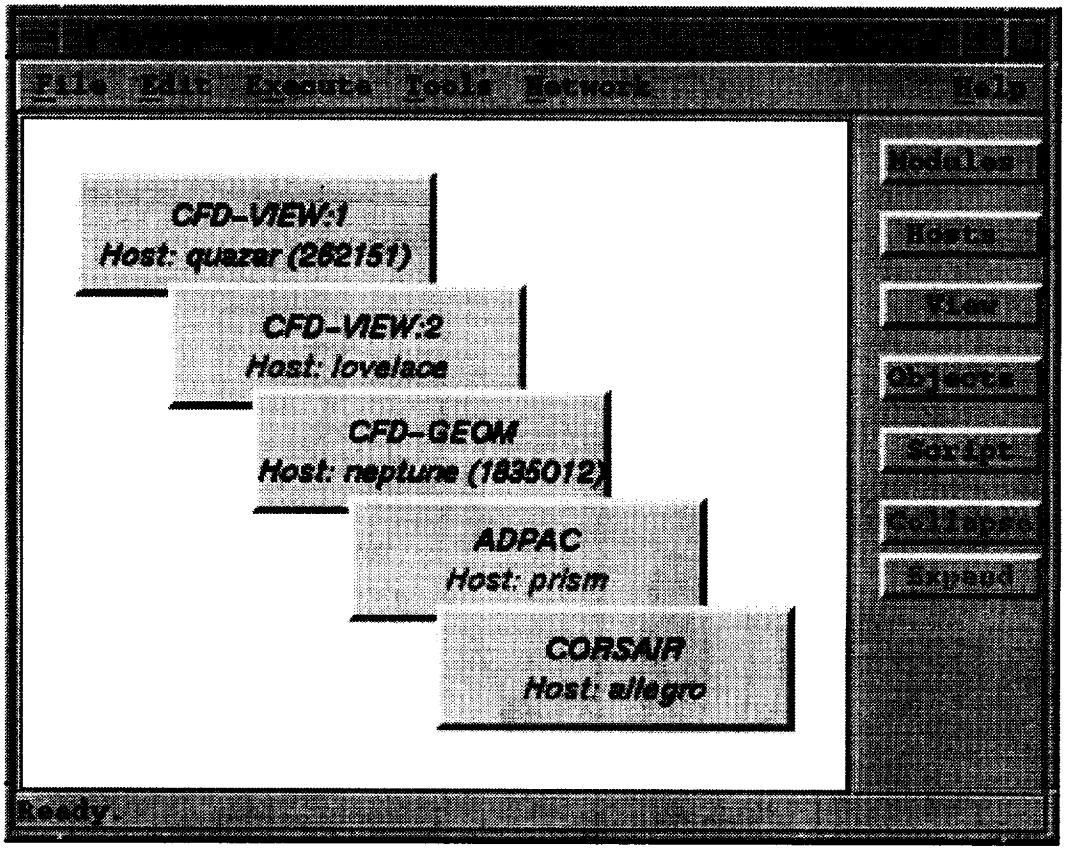

Figure 5.—VCE user interface.

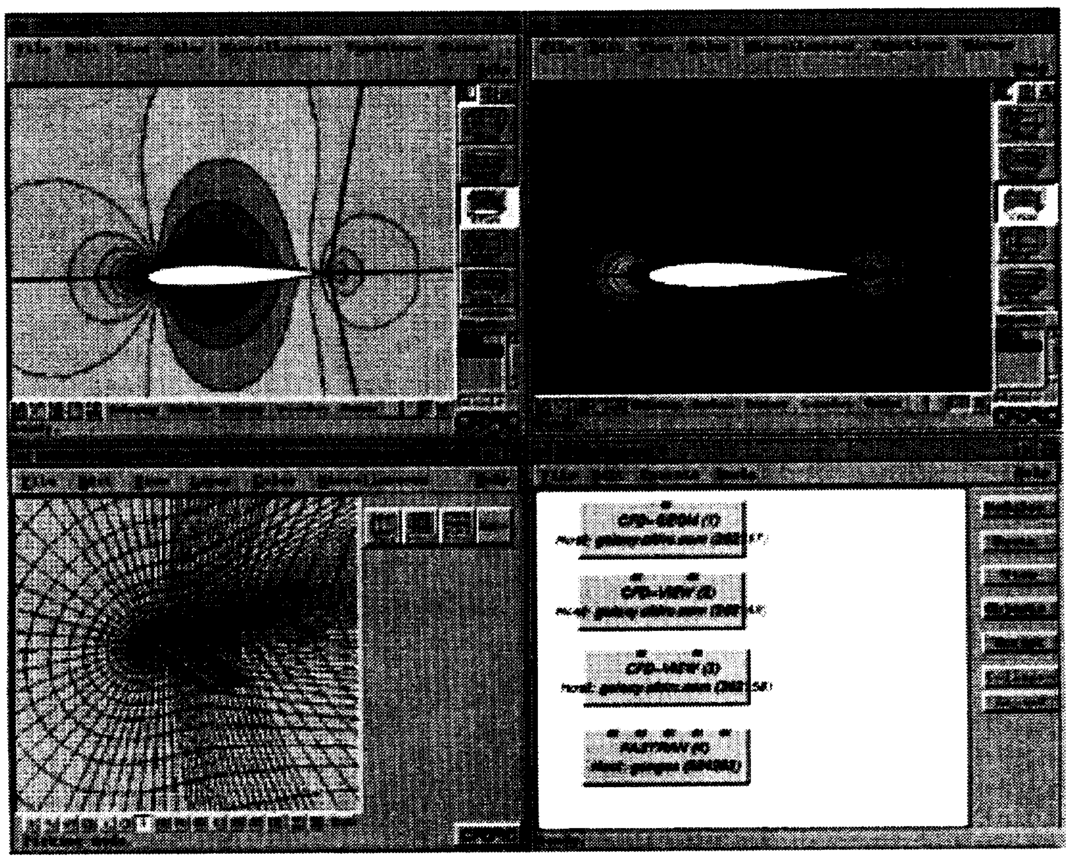

Figure 6.—Sample VCE application.

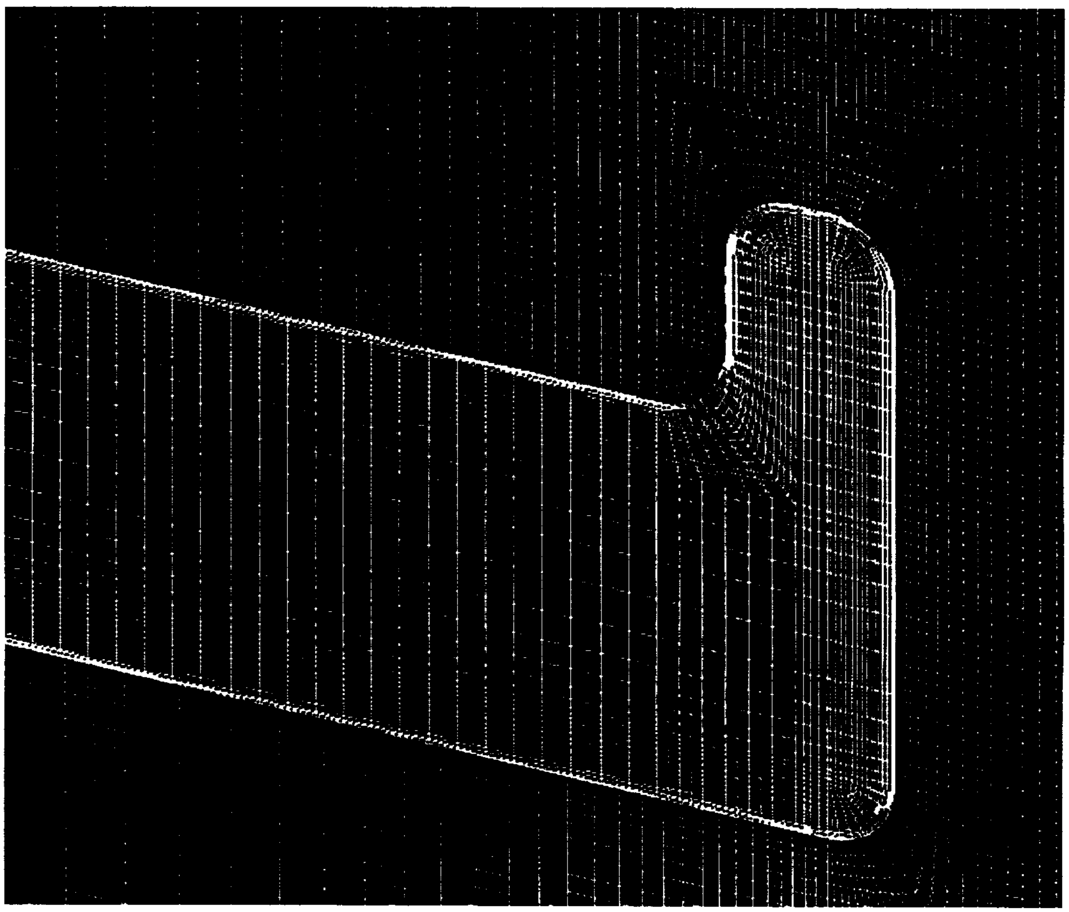

Figure 7.—Disk quenching analysis model.

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